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DETERMINATION OF ELEVATED-TEMPERATURE FATIGUE DATA ON REFRACTORY ALLOYS IN ULTRA-HIGH VACUUM

THIRD QUARTERLY REPORT

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
UNDER CONTRACT NAS 3-6010

***TRW* EQUIPMENT LABORATORIES**

CLEVELAND, OHIO

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Third Quarterly Report

for

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DETERMINATION OF ELEVATED-TEMPERATURE FATIGUE DATA ON REFRACTROY ALLOYS IN ULTRA-HIGH VACUUM

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Prepared For:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NO. NAS 3-6010

TECHNICAL MANAGEMENT

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April 19, 1965

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NOTICE

FOREWORD

The work described herein is being performed by TRW Inc. under the sponsorhip of the National Aeronautics and Space Administration under Contract NAS 3-6010. The purpose of this study is to obtain fatigue life data on refractory metal alloys for use in designing space power systems.

The program is administered for TRW Inc. by E. A. Steigerwald, Program Manager. C. R. Honeycutt and J. C. Sawyer are the Principle Investigators. T. F. Martin has aided in the design of the vibration system.

ABSTRACT

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Three of the four vacuum fatigue test chambers have been installed and are undergoing proof tests. The fourth unit will be delivered in April. The drive train has been designed and operated in air at room temperature and in vacuum at 2000°F. The transmission of the high frequency vibration through the vacuum chamber wall has been accomplished with no significant problem by mounting a stepped horn to a Curvac flange at the nodal point. Based on the measurement of deflection in the terminating horns, strains of approximately 2×10^{-3} in/in have been developed in the test specimens, however, fractures have been generally initiated in very short times in the mounting threads. Variations in specimen design are being studied to alleviate this problem

Author

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INTRODUCTION

The purpose of this investigation is to generate fatigue data for refractory alloys at elevated temperatures in ultra-high-vacuum environments. The ultimate objective of the program is to determine whether fatigue life of creep(*) is the limiting design parameter for refractory metal alloys in turbine applications.

At present, very little data exist concerning the fatigue properties of refractory metals and no design information is available at high frequencies in ultra-high vacuum. Since suitable equipment and methods for high-frequency fatigue testing in ultra-high vacuum at elevated temperatures are not available, the initial phase of the program deals with the development of test equipment which can vibrate specimens at 10 to 20 kilocycles per second at 1800 to 2200°F in a vacuum of 1×10^{-8} Torr (1.33×10^{-6} Newtons/meter^2).** In the second phase of the program, fatigue tests will be conducted on TZC and Cb132M alloys.

This report summarizes the progress in the third quarter of the program toward the manufacture of four ultra-high-vacuum environmental test chambers, and the procurement of associated test equipment. In addition, the current status of tests of the high frequency vibration system is described.

(*) Being studied on Contract NAS 3-2545

(**) Throughout the report the International System of Units will be presented along with the more conventional engineering units.

VACUUM SYSTEM

The laboratory area for the Vacuum Fatigue Program was completed during this quarter. A view of the laboratory is shown in Figure 1. This area is air conditioned and is connected to the same emergency electrical-power and recirculating cooling-water systems that serve the near-by laboratory for the Vacuum Creep Program (NAS 3-2545).

Installation of the central control console, shown in Figure 2, was also completed during this quarter, except for the vibration drive train circuits. Vacuum and temperature controls for the test stations were installed and tested. In addition, all electrical wiring between the console and the test stations was completed.

Three of the four vacuum fatigue test chambers were received and installed during this quarter. Two units have successfully completed the contractually required 100-hour vacuum proof tests at 2200°F (1204°C) with tantalum specimens. As shown in Table 1, there was no detectable increase in the oxygen content of the test material, despite the fact that the units were not baked out after roughing and the pressures while heating to test temperature reached 7×10^{-7} Torr (9.3×10^{-5} N/m^2). The 100-hour period of the test represents the time held at 2200°F (1204°C). During this period the pressure decreased from about 1×10^{-7} Torr (1.33×10^{-5} N/m^2) to below 1×10^{-8} Torr (1.33×10^{-6} N/m^2) in 6-12 hours, and continued dropping to about 5×10^{-9} Torr (6.67×10^{-7} N/m^2) near the end of the 100-hour run.

Unit No. 3, which is capable of attaining high vacuum conditions but which has not undergone proof testing, is being used for vibration drive train evaluation both in air at room temperature and in vacuum at 2000°F (1093°C).

The fourth vacuum fatigue chamber is still at the vendor's plant awaiting a qualification of the temperature gradient. This test will be completed and the unit delivered to TRW by mid-April.

VIBRATION SYSTEM

The mechanical resonant drive train is shown mounted on Unit No. 3 in Figure 3. The maximum input power available from the high frequency audio amplifier driving this unit is 200 watts. In bench tests the output has proved sufficient to break 1/4" (6.35×10^{-3}m) diameter brass specimens at room temperature.

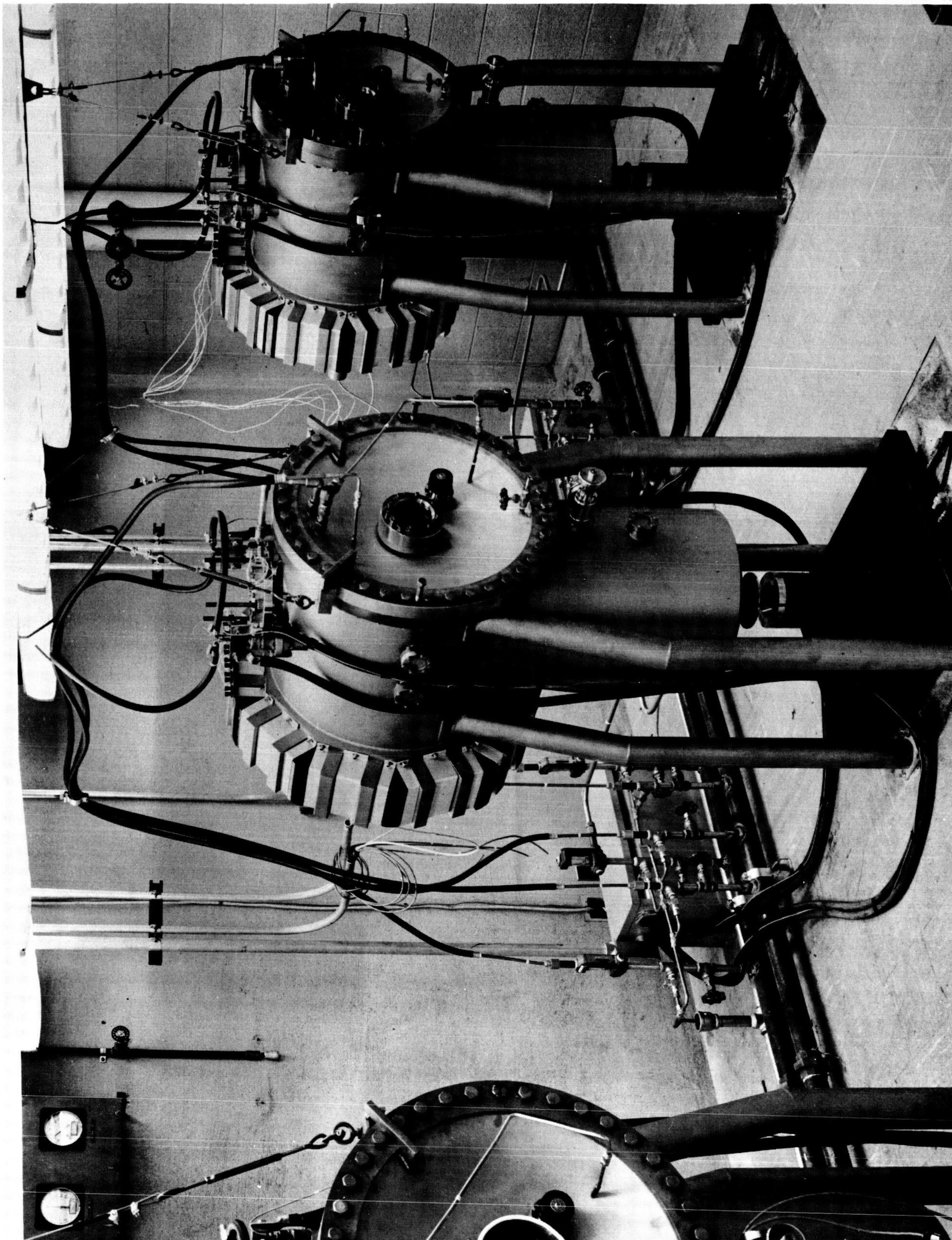

Figure 1. Vacuum Fatigue Test Units

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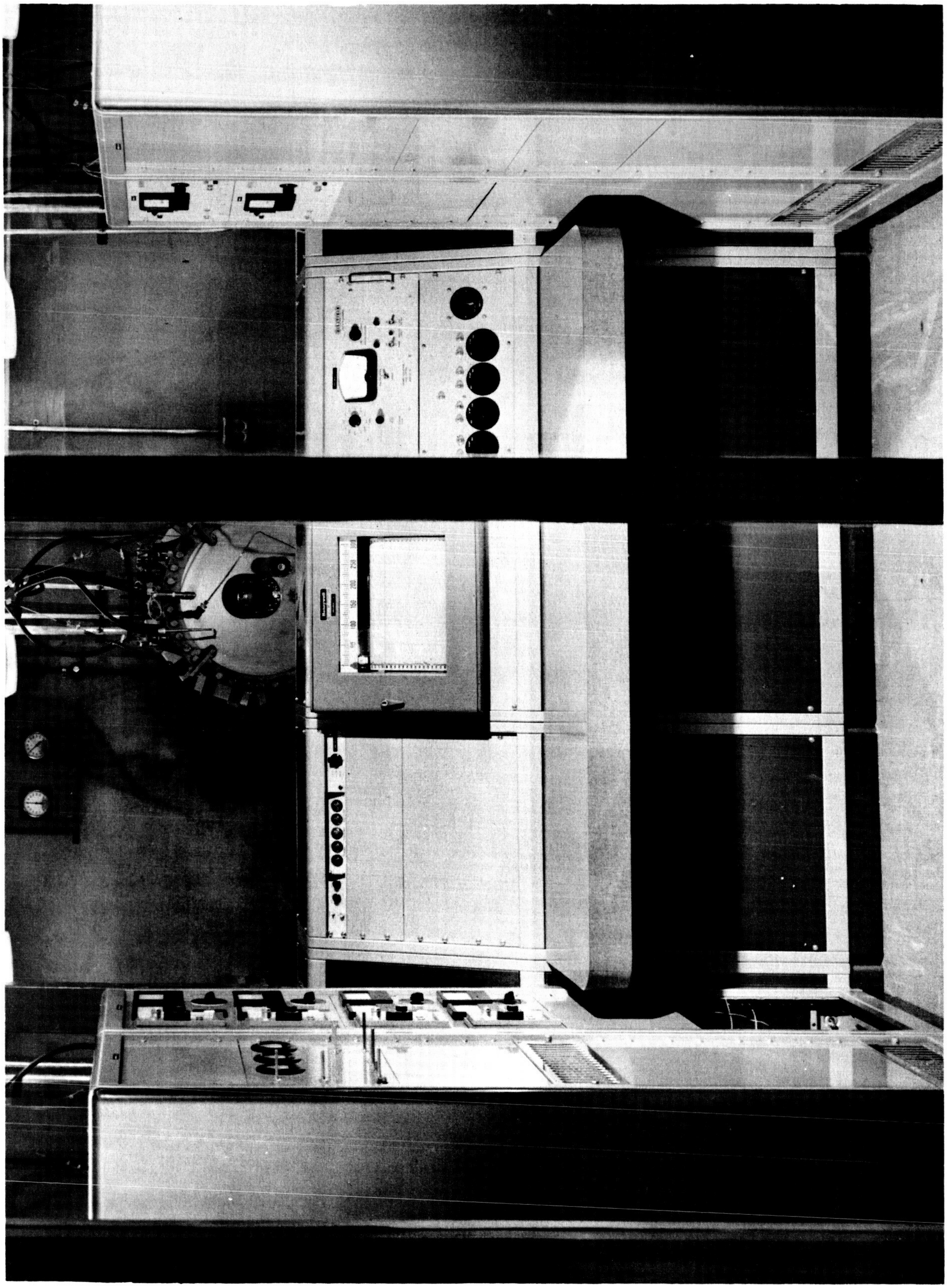


Figure 2. Central Control Console for Vacuum Fatigue Units

Table 1

Oxygen Analyses of Tantalum Specimens from 100-Hour Proof Tests at 2200°F (1204°C) in Vacuum

Vacuum Fatigue Unit	Oxygen Analyses [(a)] (weight percent)
Unit No. 1	0.0016 0.0019
Unit No. 2	0.0015 0.0017
Virgin Material	0.0011 0.0012 0.0018 0.0019
	0.0015 Avg.

(a) Analyses on test specimens were run in duplicate; four analyses were made on the virgin tantalum to establish its oxygen content and the sensitivity of the inert-gas fusion apparatus used for this comparison.

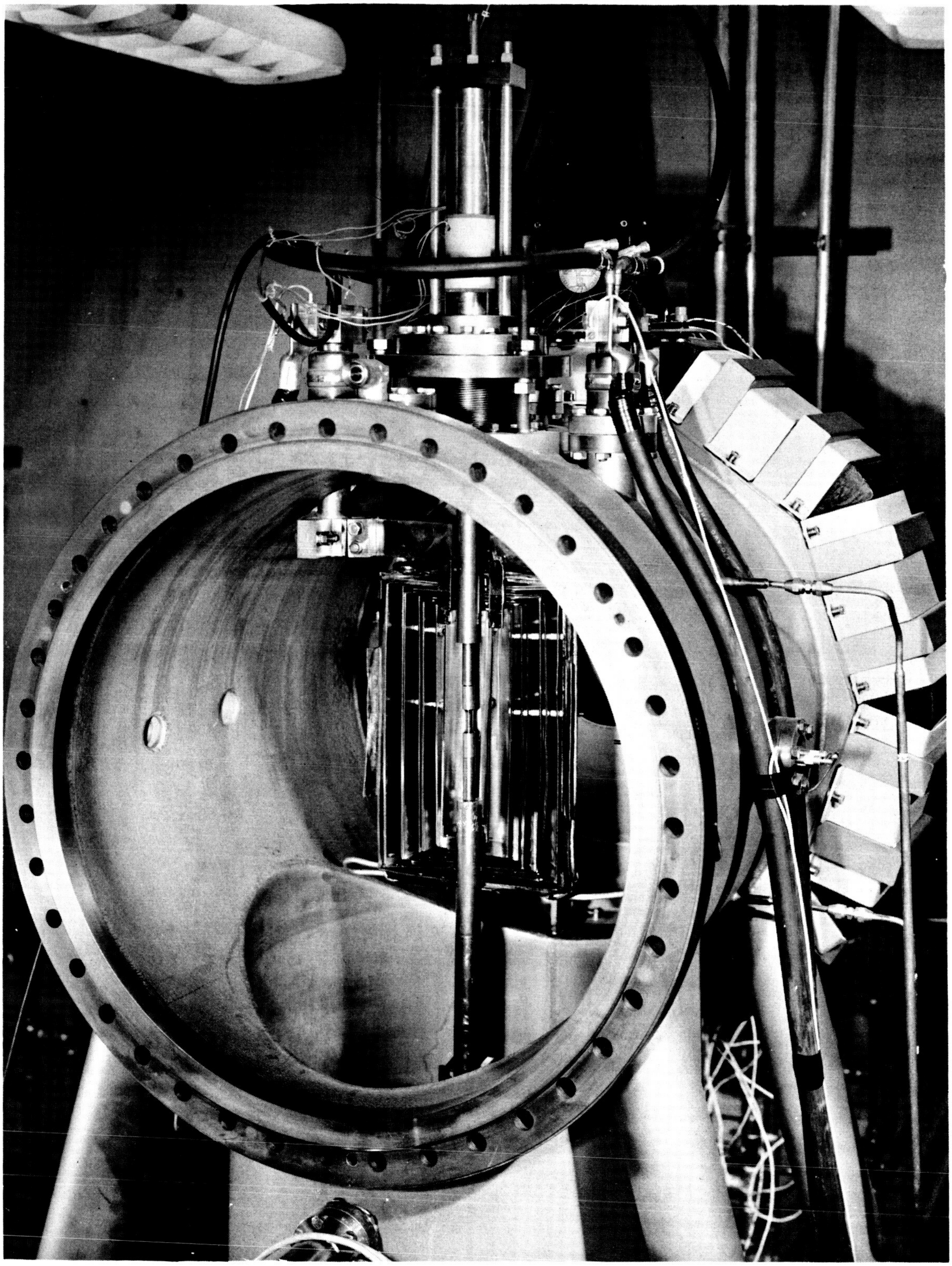


Figure 3. Vacuum Fatigue Unit with Resonant Drive Train Mounted in Place

Tests with the drive train have also shown that the input power is sufficient to heat type 304 stainless steel specimens to an equilibrium temperature of 1600°F (871°C) within a 20 minute period. This was considerably hotter than the temperature produced in yellow brass, and is presumably the result of the much higher acoustical damping capacity and lower thermal conductivity of the stainless steel. Even though the specimen was vibrated without a static load for 2 hours, no fracture was produced in any of the stainless steel specimens tested.

Tests similar to those described above have been performed at room temperature at atmospheric pressure and 2000°F (1093°C) in vacuum using TZM molybdenum alloy. No fracture was produced in this material. Measurements of the resonant frequency of the system at the elevated temperature showed that because of the specimen design and thermal expansion of the load train, the resonant frequency was less than the desired operating frequency. Revisions in specimen and load train dimensions are being made to correct this difficulty.

Up to this time a prototype amplifier capable of a 200 watt output at 20 KC has been used. Since the basic design has proved to be satisfactory, a permanent, rack-mounted model was designed and its construction is now virtually complete. Basically the amplifier consists of six 2N1073A power transistors operating in parallel-push-pull, feeding a tapped output transformer necessary for matching the crystal transducer to the amplifier. The oscillation of the system is obtained from one of two sources as desired. One source is a variable frequency oscillator built into the chassis. The other source is the end of the load train. For self exitation to occur, in this case, the vibrations picked up from the end of the specimen are amplified and properly phased before feeding into the amplifier. Figures 4 and 5 provide both block and schematic diagrams of the system being used.

A resonant frequency of 19,500 cps has been adopted as the operating frequency for the resonant drive train. This was determined from design calculations and the average resonant frequency of the commercially-available lead-zirconate-titanite (PZT) crystal transducers. Because of the high input electrical power level to the crystal, air-cooling is essential to avoid overheating.

The electrical contact to the crystal was made by soldering copper wires to the silver coating on both the OD and ID of the crystal. The connection was made at the ends of the crystal with high strength lead-tin solder containing 2 w/o silver. Three separate wires were used for each connection to provide a redundant connection.

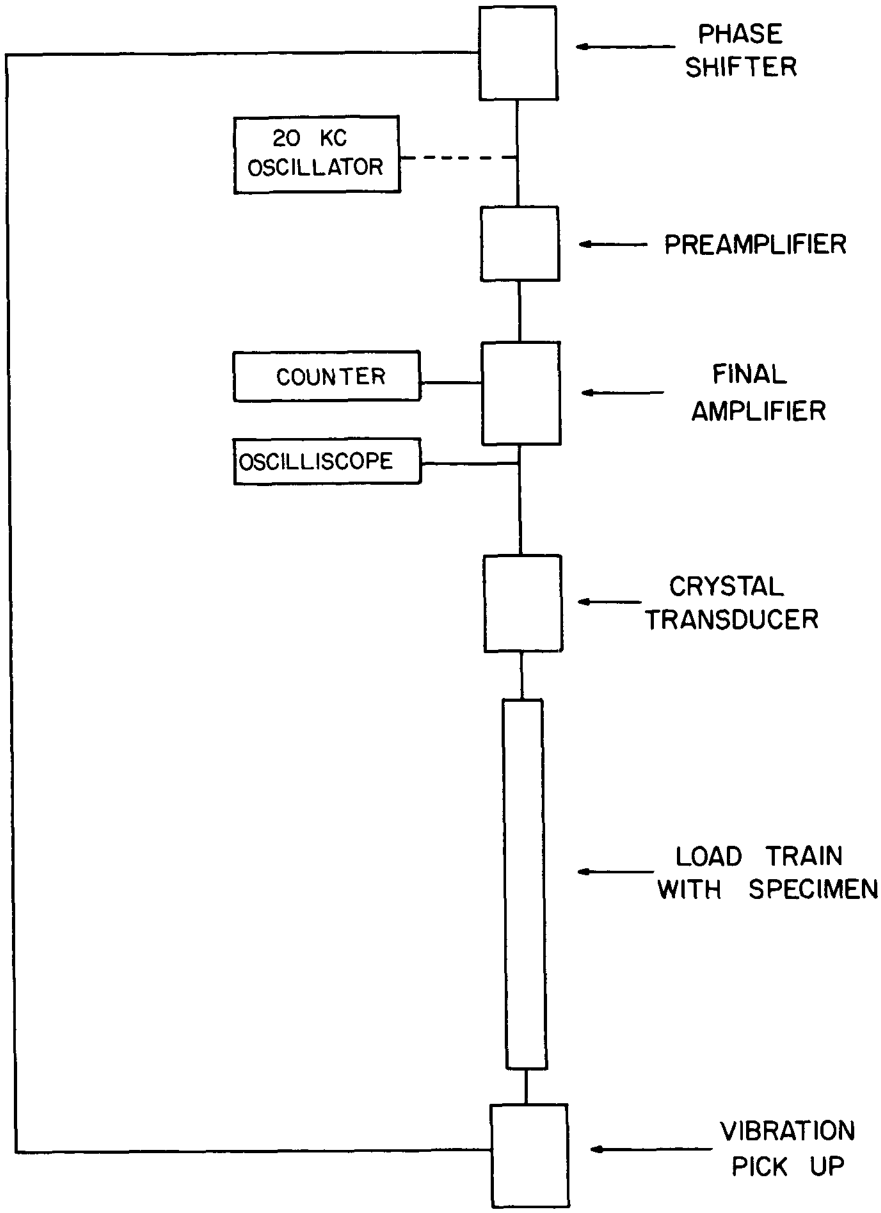


FIG. 4: BLOCK DIAGRAM OF VIBRATION SYSTEM.

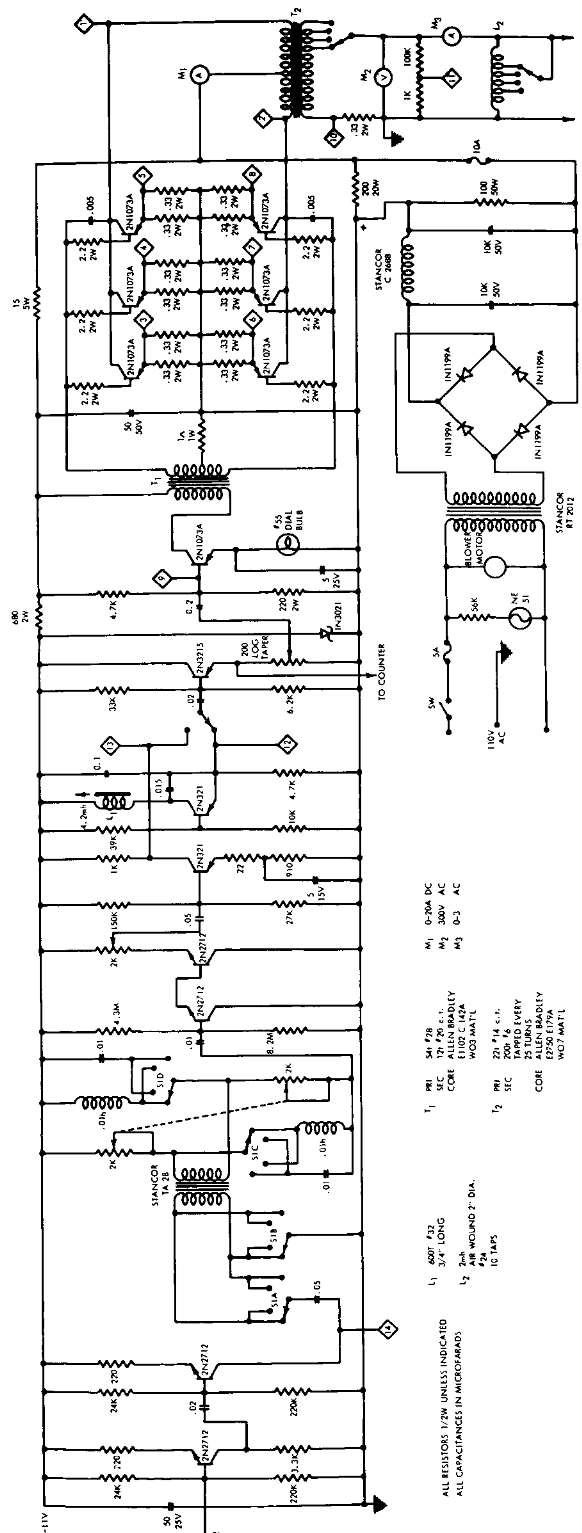


Figure 5. Schematic of 200 Watt 20 KC amplifier

The top-port design which has been adopted for the drive train consists of a titanium stepped-horn, TIG welded to a Curvac flange made of titanium (Figure 6). There appears to be no significant damping of the vibration passing through the port and vacuum integrity has been maintained thus far under tests lasting for approximately 30 hours.

The specimen design which will be used in this program is shown in Figure 7. The actual dimensions for specimens of various material depend on the damping, modulus of elasticity, and density of each material. For yellow brass, which is a low damping material, the ratio of the effective length of the specimen to the calculated wavelength of a cylindrical bar is 0.32. Similarily, for 304 stainless steel with a high-damping factor the ratio is 0.27 while for TZM a ratio of 0.30 is satisfactory. At present, work is underway to determine the optimum effective ratio for Cb132M.

Tests have shown that the radius of the fillets between the reduced and enlarged sections must be 1/4" (6.35×10^{-3}m) or greater in order to avoid fracture in the radius. Some difficulty has been encountered with the TZM specimens fracturing in the mounting threads which supposedly are located at a point of low stress. A first analysis of the problem suggests that a stress develops in the thread area because of improper specimen dimensions which shifts the nodal point out of the gauge section or because the mounting studs are too small.

Another problem area is the resonant frequency shift of the system as the specimen and hot bars are heated to temperature. Experience has shown that the frequency shift can be followed easily and resonance maintained because of the broad resonance of the crystal transducer. A decrease in resonance frequency of 600 to 800 cps has been observed as a result of heating from 70°F to 2000°F (21°C to 1093°C). If the system is to operate at maximum efficiency while hot, the resonant frequency should be 19,500 cps. To achieve this, the resonant frequency at room temperature will be higher to allow for a decrease in resonant frequency during heating arising from thermal expansion of the specimen and load train material. Attempts are being made to determine the proper specimen dimensions to allow a 19,500 Kcs resonance to be developed at 2000°F.

The Fotonic sensor which was adopted earlier as the frequency and displacment measuring device, will be replaced by a capacitive type sensor since the vendor was unable to guarantee a bakeable vacuum-tight seal in the middle of the fiber-optic bundle. A capacitive pickup, Figure 8, based on a device frequently used in turbine tests at TRW has been designed and is currently being built. Bench tests on completed parts of this pickup indicate that it will have a sensitivity of approximately 2 mils per volt (5.08×10^{-5}m/volt) which is approximately 5 times greater than the sensitivity of the Fotonic sensor.

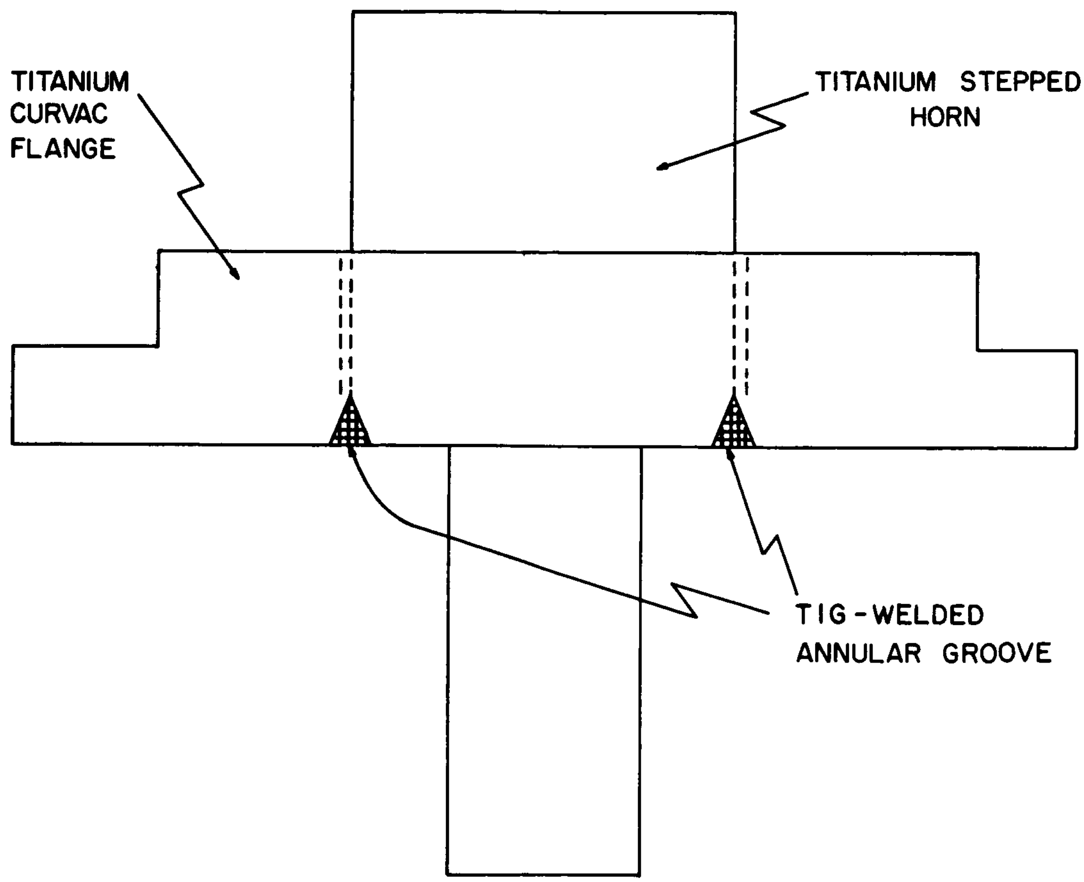
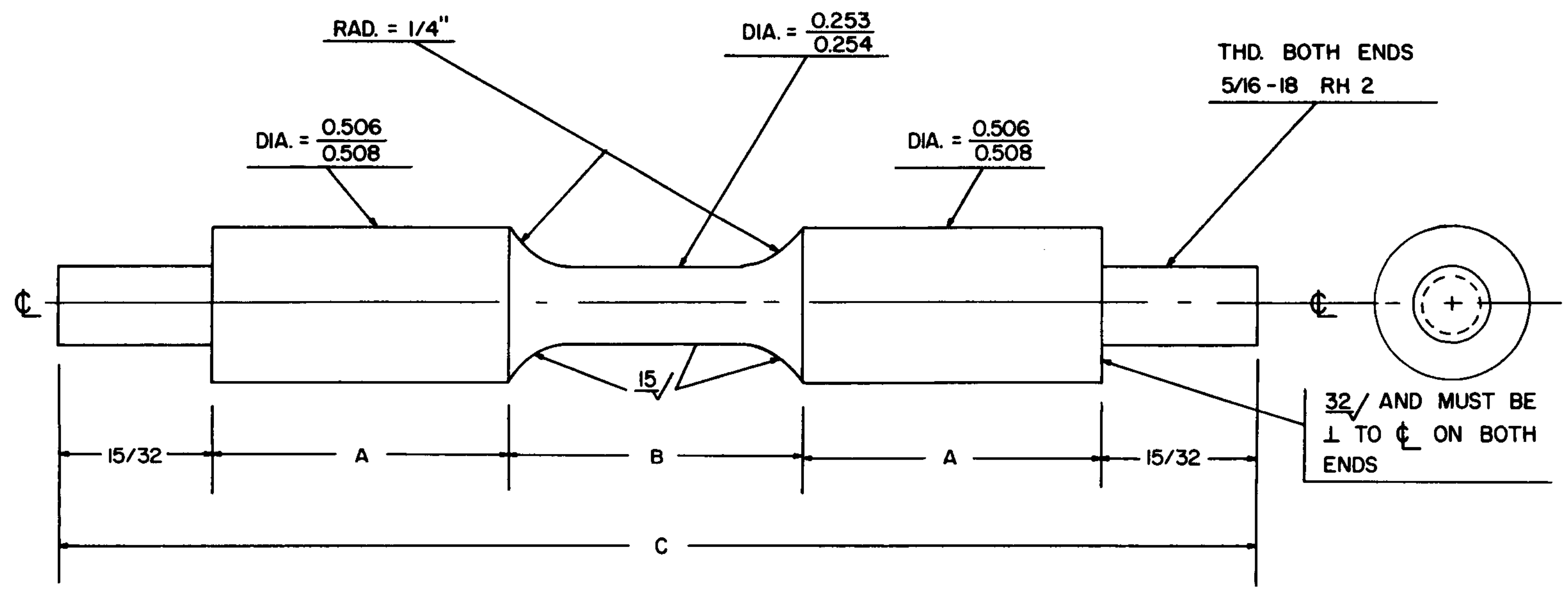


FIG. 6: TOP-PORT STRUCTURE FOR MOUNTING RESONANT DRIVE-TRAIN TO VACUUM FATIGUE UNITS.



ALL DIAMETER & THD. ENDS MUST BE CONCENTRIC ± 0.002 T.I.R.
USE MINIMUM RELIEF ON THD. ENDS
A & B ARE DETERMINED BY THE ELASTIC CONSTANT OF THE MATERIAL

FIG. 7: GEOMETRY OF VACUUM FATIGUE TEST SPECIMENS.

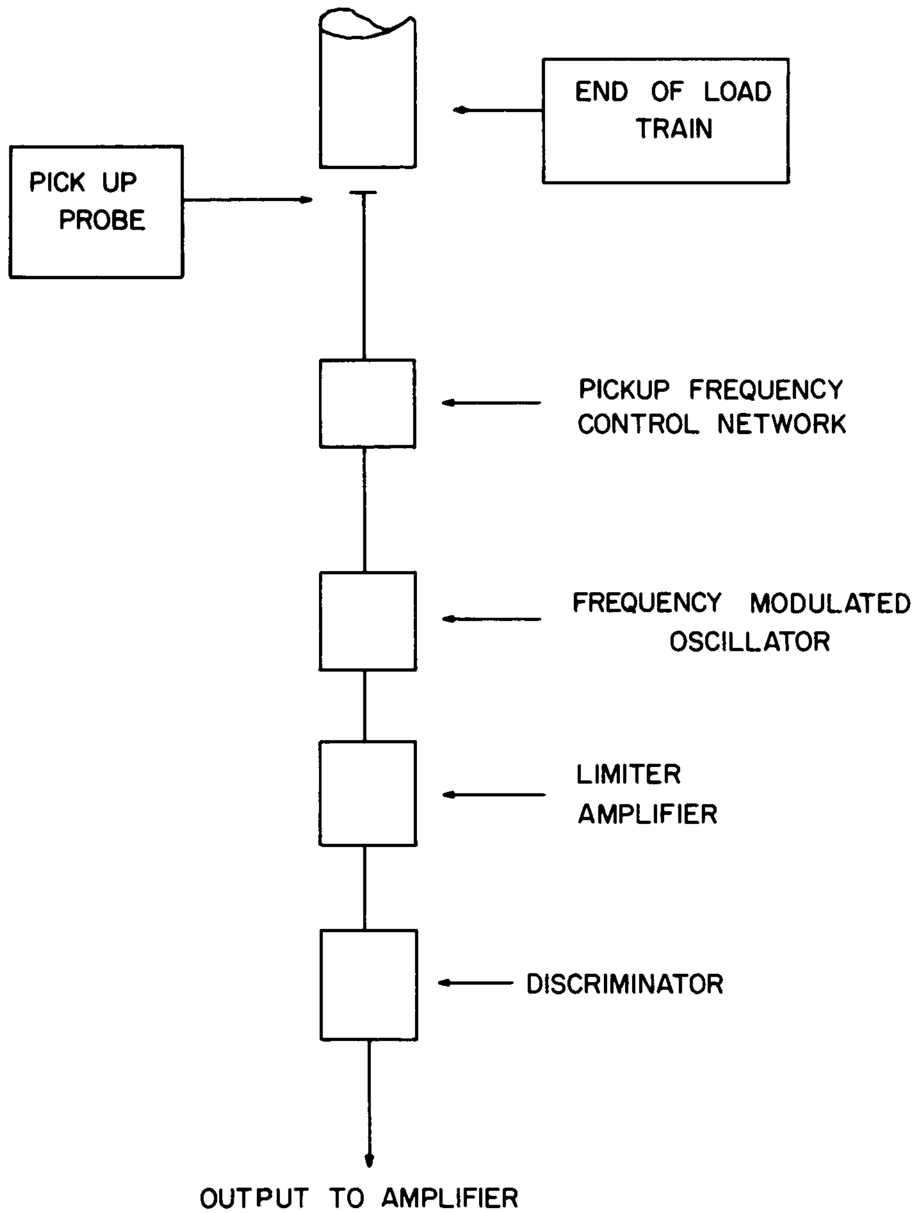


FIG. 8: BLOCK DIAGRAM OF CAPACITIVE PICKUP

For precise determination of the strain in the test specimens, an optical cathetometer will be used to measure the broadening of fine lines scribed on the fillets. From these measurements the strain in the center of the gauge length can be calculated. The cathetometer is on order and should be delivered by mid-May.

MATERIALS

The delivery of both the Cb132M and TZC alloys was originally scheduled for early April. However, the suppliers, Fansteel and General Electric, respectively have revised their promised delivery dates to mid May for both the Cb132M and TZC. Specimen design tests are being conducted with small sections of Cb132M and TZM alloys available at TRW pending delivery of the program material.

FUTURE WORK

The fourth vacuum fatigue unit will be installed and proof tests will be initiated. Temperature gradient tests will be conducted on Units No. 1 and 2. The vibration drive-train evaluation being performed with Unit No. 3 will be completed, and proof and gradient tests in this unit will begin. The electronic amplifiers and capacitive pick-ups for the vibration systems will be tested and installed in the control console. The balance of the titanium top-flange assemblies will be fabricated and installed on the units. Delivery of the test alloys will be expedited, and, where possible, alternate material will be used for preliminary fatigue testing prior to the actual delivery of the alloys now on order.

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